

DMT BIT ALLOCATION WITH IMPERFECT TEQ

Field of the Invention

5 This invention relates to a Digital Subscriber Line (DSL) transmission systems employing a Discreet Multitone (DMT) modulation scheme and, more particularly, to a system and method for optimizing bit allocation in such an implementation.

Background

10 The expanding use of Internet services, electronic mail, file transfer and other home-office applications, continues to drive the need for higher bandwidth access to the home and small business operations. The Digital Subscriber Line (DSL) technology, including Asymmetrical Digital Subscriber Line (ADSL), has provided an effective mechanism to make use of existing copper access loops and to significantly increase transmission speeds while permitting parallel usage of telephone and Internet services.

15

20 The Discreet Multitone (DMT) modulation technique is a particularly suitable way of implementing DSL in order to provide high speed and efficient use of existing bandwidth. In DMT, multiple narrow bandwidth carriers all transmit at once in parallel and each carry a small fraction of the total information. The discreet bands or subchannels are independently modulated with a carrier frequency corresponding to the center frequency of the carriers and are processed in parallel. For example, in DMT, the bandwidth may be divided into 256 sub-carriers, each with a 4 kHz bandwidth. Multi-carrier modulation requires orthogonality between all the sub-carriers and a Fast Fourier Transform (FFT) is a convenient method of achieving this modulation. At low frequencies, where copper wire attenuation is low and signal to noise ratio (SNR) is good, it is common to use a high bit rate, but at higher frequencies when unfavourable line conditions exist, modulation is relaxed to accommodate lower signal to noise ratio. Impulse noise which may be generated by electrical appliances, lightning or with a phone going off hook or ringing, is wideband in frequency and narrow in

25

30

time so it is spread over many DMT subchannels and its influence over any subchannel is relatively small. Nonetheless, the line impulse response can result in symbol distortion at the receiver. In order to offset the line impulse response, it is known to insert a cyclic prefix (M) in the time domain samples. The cyclic prefix between symbols tends to reduce inter-symbol interference. Frequently, however, the line impulse response will last longer than the typical cyclic prefix time samples and, to address this, it is known to implement a time domain channel equalizer (TEQ) algorithm. The TEQ algorithm, which applies a Fast Fourier Transform, attempts to shorten the line impulse response into M time samples. However, the response can never be exactly the finite duration of the M sample regardless of the kind of TEQ algorithm implemented. As a result, there is always channel leakage outside the M samples which causes symbol distortion or inter-channel interference at the receiver. Although the interference level is mostly very small, the interference is not evenly distributed about the channels and some channels may experience much higher interference which will cause receiver data error. In the present invention, the cross-channel interference with imperfect or inadequate TEQ is estimated and the transmitted data allocation is based on the interference levels. For example, more bits are provided to the channel with less interference, and less bits are provided to the channel with high interference. This controls the bit error rate into the desired level.

20 Summary of the Invention

The present invention provides a method of measuring the cross-channel interference in a DMT system in which line impulse influence exists after a TEQ algorithm.

25 The present invention also provides a simple, optimum implementation for bit allocation in a DMT scheme as used in a DSL application.

Therefore, in accordance with a first aspect of the present invention there is a provided a method of determining interference between channels in a digital subscriber line (DSL) 30 transmission system employing discreet multitone (DMT) modulation comprising:

determining a peak power mask level per channel (P_k);
obtaining a channel impulse value ($h(n)$) after implementation of a time equalization (TEQ) algorithm; and
multiplying the per channel power mask level and a residual impulse spectrum to obtain a
5 cross-channel interference level.

In accordance with a second aspect of the present invention there is provided a method of estimating cross-channel interference ($I(k)$) in a discrete multitone (DMT) communication system implemented in a digital subscriber line (DSL) application, the DMT system
10 employing inter-symbol cyclic prefix (M) and time equalization (TEQ), the method comprising:

- a) measuring a total channel impulse response ($h(n)$) value remaining after TEQ;
- b) zeroing M main coefficients from $h(n)$;
- c) performing fast fourier transform (FFT) analysis on the result of step b); and
- d) obtaining $I(k)$ by multiplying the result of step c) with a measured maximum power per channel value.

In accordance with a further aspect of the present invention there is provided a method of allocating bits per channel in a DMT communication system implemented in a DSL application, the system employing inter-symbol cyclic prefix and time equalization, the
20 method comprising:

- performing a first bit allocation algorithm to obtain a first bit per channel value and a first power per channel level;
- obtaining a cross-channel interference value based on a measured impulse response;
- 25 obtaining a noise value by adding the cross-channel interference value to an interference noise value;
- obtaining a second power mask per channel level based on a pre-calculated power per channel level; and
- implementing a second bit allocation algorithm utilizing the noise value, a signal to noise ratio and the second power mask per channel level to obtain a final bit per channel allocation.

Brief Description of the Drawings

The invention will now be described in greater detail with reference to the attached drawings
5 wherein:

Fig. 1 shows the frequency and time relationship in a discreet multitone (DMT) implementation;

Fig. 2 is a block diagram of a basic DMT transmitter;

Fig. 3 is a basic block diagram of a DMT receiver;

10 Fig. 4 shows at a high level the bit allocation process; and

Fig. 5 illustrates at a high level the interference measurement process.

Detailed Description of the Invention

15 As discussed previously, DMT operates in the frequency domain. Each DMT subchannel (there are many being communicated in the parallel) lasts a long time but operates in a narrow frequency band of the total bandwidth. As shown in Fig. 1, the total carrier frequency is divided into many narrow bands, and each is modulated with information in the time domain. Bits are allocated to each subchannel for transmission and at the receiver, the bits in each subchannel are demodulated to retrieve the communicated information.

20 In the DMT based DSL system N point FFT is used to transform N frequency subchannel carriers having quadrature amplitude modulation (QAM) modulated thereon into N point time domain samples. Thus in Fig. 2, input data is provided to a serial to parallel encoder.

25 The output has N QAM symbols imparted thereto and, following the Inverse Fast Fourier Transform (IFFT) 12, the data is broken into time domain samples and, following the parallel to serial converter 14 the time domain signal may be passed through a digital to analogue converter (not shown) and on to the output line. Typically a cyclic prefix (M) 16 is inserted into the time domain signal prior to transmission.

30

The received signal as shown in Fig. 3, is passed through an A to D converter (not shown). Typically, the cyclic prefix M has a smaller value than N for minimum redundancy. Because most line impulse responses lasts much longer than M time samples, a time domain channel equalizer (TEQ) 18 is required. There are several TEQ algorithms available that are used to 5 shorten the channel into M time samples. However, the channel can never have an exactly finite duration with only M samples, no matter what kind of TEQ algorithm is applied. As a result, there is always channel leakage outside the M samples which will cause symbol distortion or inter-channel interference at the receiver. Although the interference level is usually very small, the interference is not evenly distributed between the channels, and some 10 channels may experience much higher interference levels which, in turn, will cause receiver data error.

Fig. 4 shows pictorially the bit algorithm scheme, including cross-channel interference measurement according to the present invention. Typically, the bit allocation algorithms use 15 the following information to decide how many bits should be transmitted on each channel: power mask or maximum transmission power at each channel; noise level including near end cross talk (NEXT) and far end cross talk (FEXT), the signal to noise ratio (SNR) requirements for bit transmission and the channel impulse response which gives channel 20 attenuation for each channel. The output of the bit allocation algorithm provides: the number of bits to be transmitted per channel and the corresponding transmitting power for each channel.

In Fig. 4, the first bit allocation algorithm 20 takes inputs $N(k)$ which is the measured noise 25 power for each channel; $P(k)$ which is the power mask level which limits maximum transmission power for each channel; and $SNR(bn)$ which is the signal to noise ratio requirement when bn bits are transmitted at the given channel. As shown in Fig. 4, the outputs of the first bit algorithm are $b(k)$ which is the number of bits to be transmitted at channel k in accordance with the bit allocation algorithm 20 and $Px(k)$ which is the transmission power for channel k .

The interference measurement block 22 of Fig. 4 measures the cross-channel interference level $I(k)$ based on the total channel impulse response $h(n)$ after the time equalization (TEQ) algorithm and the transmission power input $P(k)$ from the first allocation algorithm. The interference $I(k)$ which is the statistically combined interference to channel k from all other channels will be added to the measured noise level $V(k)$ and the result $V_1(k)$ becomes the modified noise power input which is provided to the second bit allocation algorithm 24. The interference block 22 also outputs the new power mask $P_1(k)$ for the second bit allocation algorithm 24. The reason for a new power mask function is that the cross-channel interference $I(k)$ is signal dependent. Since the total noise level increases with cross-channel interference noise being added, the signal transmitting power will be increased as well. Consequently, the cross-channel interference $I(k)$ will be increased which otherwise would result in a repeating loop. The interference block 22 calculates the new power mask $P_1(k)$ based on the pre-calculated transmitter power $P_x(k)$ and the maximum power transmitted will be fixed at $P_1(k)$. The calculated interference is based on the maximum possible transmission power $P_1(k)$. With the new power mask $P_1(k)$ and noise power $V_1(k)$, the second bit allocation algorithm is implemented to obtain the final bit allocation $b_1(k)$ and its corresponding transmitting power $P_{x1}(k)$ which takes into account the aforementioned cross-channel interference.

One way to determine the new power mask function is described as follows:

Let $P_{max} = \max(P_x(k))$, then we have

$$P_1(k) = \begin{cases} P_{max}, & P(k) \geq P_{max} \\ P(k), & P(k) < P_{max} \end{cases}$$

The above equation means that P_{max} is chosen as the new maximum transmission power for all channels unless it is above the original mask power, in which case the original mask power $P(k)$ is retained. In theory, with the newly calculated mask power, it is possible to calculate statistic interference level in all channels. However, the precise calculation is still a very complicated procedure that involves the computation of each channel interference from

all other channels. Fig. 5 shows a simple approximate upbound or upper limit for the cross-channel interference with given total channel impulse response $h(n)$ after TEQ.

As mentioned before, with M point cyclic prefix being added in the transmit signal, there will be no interference if the total channel response $h(n)$ is of finite length lasting only M sample points. The block “zeroing M coefficients” 26 in Fig. 5 sets those M coefficients to zeros and the remaining coefficients in $h(n)$ are then the source of the inter-channel interference. Taking Fourier transform in FFT block 28 of the remaining channel response and multiplying them at multiplier 30 with $P_1(k)$ gives out the upbound for the cross-channel interference $I(k)$.

To get the interference level, it is possible to use either $I(k)$ or the envelop of $I(k)$, or some other modificatied form of $I(k)$. $P_1(K)$ can also be modified based on $P_x(k)$ and $P(k)$. In the $P_1(k)$ calculation, P_{max} can be replaced with a local maximum of $P_x(k)$, such that $P_{max}(k) = \max_{k1}(P_x(k+k1))$, for $-C < k1 < C$, where C is predetermined value to decide the neighboring area around K . If $P_1(k)$ is chosen such that $P_1(k) = \min([\text{SNR}(\max(bn))][\max(V(k))], \max(P(k)))$, the first bit allocation in Fig. 4 becomes unnecessary. In this way, one half the computation for bit allocation is saved by running it only once and $P_1(k)$ becomes a constant which is the maximum potential transmitted power at each channel.

Although a preferred embodiment of the invention has been disclosed and illustrated, it will be apparent to one skilled in the art that numerous alternatives can be made to the invention without departing from the basic concept. It is to be understood, however that such changes will fall within the true scope of the invention as defined by the appended claims.